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BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Extended LM Electrical Power Supply Alternatives - Case 320

DATE: February 26, 1969

FROM: R. D. Raymond

ABSTRACT

A review of the LM electrical power subsystem alternatives indicates that batteries are the best choice for lunar stay times of about 1.5 days. For longer durations improved batteries, fuel cells, and solar cell/battery systems are all reasonable contenders, based on weight optimization, with the best choice greatly biased by the maximum duration required. The prospects are not good for battery energy density improvements that would make batteries competitive for durations longer than about 2 or 3 days. Therefore, beyond about 3 days only fuel cells and solar cell/battery configurations should be evaluated.

Even if the specified stay time for an extended LM is within the feasible capability of an improved battery system, i.e., about 3 days, development of new batteries may not provide a good trade off with fuel cells or solar cell/batteries when considering factors such as development risk and operating time flexibilities. Although higher energy battery materials have been tested in laboratories and used in small battery applications, the development cycles for large spacecraft batteries are long and the results are uncertain.

(NASA-CR-104009) EXTENDED LM ELECTRICAL POWER SUPPLY ALTERNATIVES (Bellcomm, Inc.) 7 p

N79-72790

Unclas
00/33 11440

FF No. 602
(PAGES)
CR-104009
(NASA CR OR TMX OR AD NUMBER)
(CODE)
(CATEGORY)
[redacted]

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MEMORANDUM FOR FILE

INTRODUCTION

Much has been accomplished and discussed with respect to spacecraft electrical power supplies. Nevertheless, the electrical power subsystem of the LM remains a particularly constraining feature for missions requiring long operating times and heavy useful payloads. The only relief of this constraint that is within the control of the power subsystem requires an improvement in the energy-to-weight ratio (energy density) of the power subsystem.

The scope of this report is simply to put into proper context the highlights of issues related to energy versus weight optimization of possible LM power sources. The questions discussed here include (1) why does the LM have a battery power supply; (2) can or should the batteries be improved; and (3) what else could do the job?

THE LM POWER REQUIREMENTS

The Apollo LM requires a power source for variable loads of about 0.5 to 2.5 KW at 28 VDC[1]. For the nominal lunar landing mission, with 1.5 days staytime, the LM descent batteries can provide up to about 47 KWH and the ascent batteries can provide up to about 17 KWH of energy.

Extended LM missions would require approximately the same range of power levels as the existing LM. The LM descent stage energy requirements projected for extended missions of 3 to 7 days range from about 1.5 to 3 times that now provided by the LM descent stage (or 70 to 140 KWH). Ascent stage power supply requirements are assumed to remain essentially unchanged.

THE LM POWER SUBSYSTEM AND ALTERNATIVES

Many classes of electrical power subsystems are applicable to spacecraft systems. However, application of one system optimization factor, obtaining a specified power output for a fixed time period with the least system weight, quickly eliminates most of the choices. This selection is illustrated by Table 1, which summarizes the general capabilities of space power subsystems in the time frame of the LM development, as reported in Space Power Systems Engineering(2).

Since the LM requires less than 2KW average power for a period of less than 2 days, batteries appear to be a good choice. Fuel cells are also a feasible choice and, in fact, were the initial selection for LM. Chemical dynamic systems are not serious contenders, however, since they are primarily suitable only for a few hours of operation.

The type of battery (silver oxide--zinc) used for LM power was selected on the basis of the best energy-to-weight ratio available in a space qualified battery. The advisability of this choice is supported in a Bellcomm memorandum by W. O. Campbell(3). The LM descent stage power uses four 134 pound silver oxide - zinc batteries rated at 400 AH each (approximately 11.7 KWH each). The energy density of these batteries is, therefore, about 87 watt-hours per pound.

EXTENDED LM POWER SUBSYSTEM ALTERNATIVES

Useful extension of the LM operating time will require more electrical energy. Several feasible alternatives for this additional energy can be selected by reference to Table 1. These power system classes are not rigidly separated in the time domain because considerable energy density overlap exists now and new developments are continually increasing the overlap. It appears that LM operating times of about 3 days can be accommodated by either batteries or fuel cells. In addition, hybrid systems (combining power classes) are feasible options, e.g., one proposed by GAEC combines solar cells and existing descent stage batteries.

Since the use of batteries for LM power becomes marginal with respect to weight optimization as the operating time requirement approaches 3 days, even with new battery developments batteries do not appear to be competitive with fuel cells or hybrid systems if growth potential beyond 3 days is seriously considered. An in-depth study of power system alternatives would be necessary to optimize the LM power system for longer staytimes with respect to weight, development risk, operating flexibility and cost.

Appendix A summarizes pertinent aspects of battery development. Feasible battery improvements include uprating the existing LM silver oxide-zinc cells a few percent or developing alternative batteries with higher energy electrode materials. However, the current state-of-the-art of battery production does not allow a prediction that new materials, with demonstrated higher energy density capability in laboratory tests or small battery applications, can be incorporated readily into large spacecraft qualified batteries.

R. D. Raymond

2033-RDR-sep R. D. Raymond

TABLE 1. SPACE POWER SYSTEMS APPLICATIONS*

POWER OUTPUT REQUIREMENT	APPROXIMATE OPERATING TIME REQUIREMENT		
	<2 Days	1-30 Days	>30 Days
UNDER 5 KW	1. Battery 2. Chemical Dynamic	1. Fuel Cell	1. Photovoltaic 2. Radioisotope 3. Solar Static
OVER 5 KW	1. Chemical Dynamic 2. Cryogenic Chemical Dynamic	1. Cryogenic Chemical Dynamic 2. Fuel Cell	1. Solar Dynamic 2. Nuclear Dynamic

*Considerable overlap exists in the energy capabilities of this simplified matrix, but weight limitations tend to constrain the power system choices as shown.

REFERENCES

1. Universal Mission Modular Data Book, LED-500-19, Grumman Aircraft Engineering Corporation, Bethpage, N. Y., 1968.

2. Szego, G. C. and Taylor, J. E., Space Power System Engineering, Progress in Astronautics and Aeronautics, Volume 16, Academic Press, Inc., 1966.

3. Campbell, W. O., Apollo Battery Problems, Memorandum for File, Bellcomm, Inc., May 17, 1968.

APPENDIX A

Battery Improvement Considerations

1. LM Battery Uprating

The silver oxide-zinc battery manufactured by Eagle-Picher for the LM descent stage could possibly be uprated by improved manufacturing and testing methods. Previous actions taken to investigate this possibility were discussed in a memorandum by R. D. Raymond[1]. A proposed 5 percent improvement in the battery would raise the energy density to over 90 watt-hours per pound.

2. Silver Chloride-Magnesium Battery

New materials for battery electrodes might provide improvements in the energy density of spacecraft batteries. One example is described in an article by H. J. Strauss, which claims $AgCl/Mg$ battery energy yields are 50% higher than for Ag_2O/Zn batteries[2]. The comparison given is 75 watt-hours per pound versus 50 watt-hours per pound. This claim is misleading, as indicated by the following paragraph.

A report on small silver-zinc batteries presented by M. J. Sulkes in the 22nd Annual Power Sources Conference shows that long-life rechargeable (100 cycles) silver-zinc batteries can exhibit an energy density of 52 watts-hours per pound at rated capacity and the same battery has an initial charge (or one-cycle capacity) of 72 watt-hours per pound[3]. This is probably better than the claim made for the $AgCl/Mg$ battery because the $AgCl/Mg$ battery weight does not include electrolyte; it must be plunged in salt water to activate it. Although this method of activation is advantageous in certain marine applications, it would be a penalty for LM use because excess water is not an available commodity.

Neither of the above batteries is comparable in

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1. Raymond, R. D., LM Descent Battery Uprating for Three-Battery Capability, Bellcomm, Inc., July 15, 1968.

2. Strauss, H. J., Silver Chloride-Magnesium A Powerful Battery, Burgess Battery Division, Clevite Corporation, November, 1968.

3. Sulkes, M. J., Improved Army Silver-Zinc Batteries, U. S. Army Electronics Command, May, 1968.

design or capacity to the LM spacecraft batteries. Therefore, it is difficult to obtain a meaningful comparison to the 90 watt-hours per pound achievable by the LM silver oxide-zinc battery.

3. The Search for High Energy Battery Materials

A paper presented at the 22nd Annual Power Sources Conference characterizes the state-of-the-art of battery development. The following is a quote from this paper by L. L. Wikstrom[4].

"Although the battery is the oldest electrical power source, the design of a battery system is to a great degree still based on empirical state-of-art trial and error methods. Until recently this was by necessity, as a true understanding of electrochemical reactions occurring in a battery was not at hand. This is no longer the case as electrochemists now understand these reactions adequately and have characterized many of the simpler electrochemical reactions."

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4. Wikstrom, L. L., Study of Electrochemical Reduction of Organic Materials, New York University, May, 1968.

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